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Date of Deposit August 28, 2001

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PHASE MODULATION POWER SPREADING USED TO REDUCE RF OR MICROWAVE TRANSMITTER OUTPUT POWER SPUR LEVELS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application is related to commonly-owned copending patent application entitled; "Low Order Spur Cancellation Mixer Topologies," by Mark Kintis, Serial No. _____, filed on even date, Attorney Docket No. 12-1212.

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0002] The present invention relates to RF and microwave mixers and more particularly to mixers for up-converting RF and microwave signals which incorporates phase modulation power spreading to reduce the power level of spurious output signals (also known as spurs).

2. Description of the Prior Art

[0003] Mixers are generally known in the art and are used in various applications for up-converting or downconverting microwave and RF signals having a frequency f_1 to a higher or lower frequency for by way of a local oscillator. Such mixers are non-linear devices with two input ports and one output port. One input port is used for a microwave or RF input signal

having a frequency f_1 while the other input port is for a local oscillator signal having a frequency f_2 . When such signals are applied to the input ports, the following signals are generated at the output port: the original signals f_1 , f_2 ; the sum and difference of the signals f_1 and f_2 ; harmonics of the original signals; as well as the sum and differences of each of the harmonics of the signals f_1 and f_2 . In general, the output signals available at the output of a mixer are provided by equation 1 below:

$$(1) \quad f_{\text{output}} = \pm M^* f_1 \pm N^* f_2, \text{ where } M \text{ and } N \text{ are integers and the sum } |M| + |N| = \text{"order" of the mixer output signal frequency.}$$

[0004] When the mixer is used as an upconverter, the desired output frequency of the mixer may be $f_1 + f_2$ or $f_2 - f_1$, for example. Similarly, when the mixer is used as a downconverter, the desired output of the mixer may be $f_1 - f_2$ or $f_2 - f_1$. The balance of the signals generated by the mixer are spurious output signals or simply spurs. Such spurs are well known and relate to the inherent characteristics of the mixers, for example, as disclosed in "Effects of Offsets on Bipolar Integrated Circuit Mixer Even-Order Distortion Terms", by Coffing et al., IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, vol. 49, no. 1, January 2001, pages 23-30.

[0005] The spurs at the mixer output port can often times be filtered out with simple low pass or band pass filters. Because of this, the power level of many of the spurs decreases the further the spur frequency is away from the desired output frequency. Thus, due to the low power level, many of the spurs are simply ignored.

[0006] The Federal Communication Commission requires that the out of band spurious signals be below a given power level within a given bandwidth for transmitters. One typical requirement for satellite downlinks is that the signals must not exceed 65 dBc within any 4 KHz frequency bandwidth window. Unfortunately, in certain applications this requirement is difficult if not impossible to meet.

[0007] FIG. 1 illustrates a typical upconversion example used for a transmitter 20. The transmitter 20 includes two mixer stages, generally identified with the reference numerals 22 and 24. Each mixer stage 22 and 24 includes two input ports and one output port. In this example, a 750 MHz RF input signal, identified with the reference numeral 26, is applied to an input port of the first mixer stage 22. The 750 MHz input signal 26 is to be upconverted to 18.25 GHz. As such, the local oscillator signals for the two mixer stages 22 and 24 are selected as 3 GHz and 16 GHz, respectively.

[0008] One output signal of the first mixer stage is 2.25 GHz plus a number of spurious output signal or spurs as discussed above. Some of the spurs are filtered out by a simple intermediate frequency (IF) filter, such as the IF filter 28. The output of the IF filter 28 is applied to the input port of the second mixer stage 24. The output of second mixer stage 24 is typically applied to a power amplifier and subsequently to a transmit antenna (not shown).

[0009] Unfortunately, each of the mixer stages 22, 24 produces spurs with significant power levels that can appear in the transmitted output. More particularly, the spurious output signals or spurs from both the first and second mixer stages 22 and 24 are generally significant because of a relatively high power local oscillator signal is required to achieve RF frequency conversion. Typically, the power requirement for the local oscillator signal is at least 20 dB higher than the incoming RF signals. Unfortunately, the relatively high power level spurs produced from the first mixer stage 22 are mixed with the relatively high power level of the local oscillator signals at the second mixer stage 24. Consequently, in addition to the 18.25 GHz desired output signal, relatively high power level spurs are also generated which exceed the 65dBc power level requirement. Referring to FIG. 2, a relatively high power level spur is generated, identified with the reference numeral 32. This spur 32 represents the leakage from the second mixer stage 24. As shown in FIG. 2, the spur 32 exceeds the 65 dBc requirement. The 65 dBc reference level is identified with the segments 38 and 40. Thus, in order to meet the FCC requirement, a narrow band output filter is required to filter out the spur 32. Such an output filter would be relatively expensive and possibly degrade the transmitter in band performance. As such, there is a need for a mixer configuration, which would reduce the power level of the spur

signal resulting from leakage of the local oscillator in the second mixer stage of a transmitter to within acceptable limits.

SUMMARY OF THE INVENTION

[0009] Briefly, the present invention relates to a mixer, for example, a two stage mixer, for use in a transmitter application. In order to reduce the power level of out of band spurious output signals or spurs, phase modulation power spreading is used. In particular, each mixer is phase modulated or inverse phase modulated, for example, by a direct sequence phase shift keying (BSK) modulator, to spread the power levels of the spurs over a wider bandwidth instead of concentrating the power levels at single frequencies. The system is easily implemented by phase modulating the first mixer stage with a first pseudorandom number (PN) code and inverse phase modulating the second mixer stage with the same PN code. By utilizing phase modulation, the need for relatively complex and expensive second and third order filters is eliminated to reduce the power level of spurs, such as those spurs resulting from the leakage of the local oscillator in the second mixer stage.

DESCRIPTION OF THE DRAWINGS

[0010] These and other advantages of the present invention are readily understood with reference to the following specification and attached drawings wherein:

[0011] Fig. 1 is a block diagram of a known two stage mixer, shown with a 750 MHz input signal.

[0012] Fig. 2 is a graphical illustration of the signal power levels as a function of frequency of the desired output signal and the spurious output signal from the local oscillator in the second mixer stage for the mixer illustrated in Fig. 1.

[0013] Fig. 3 is a block diagram of two stage mixer in accordance with the present invention.

[0014] Fig. 4 is a graphical illustration of the signal power levels as a function of frequency of the desired output signal and the spurious output signal from the local oscillator in the second mixer stage for the two stage mixer illustrated in Fig. 3.

[0015] Fig. 5 is a graphical illustration of the signal power levels as a function of frequency of the desired output signal and the spurious output signal resulting from the leakage from the local oscillator in the second mixer stage, applied to the input of the second mixer stage of the mixer illustrated in Fig. 3.

DETAILED DESCRIPTION

[0016] The present invention relates to a two stage mixer for use in a transmitter. In accordance with the present invention, in order to reduce the power levels of the spurs, the power levels of the spurs are spread out over a relatively wide bandwidth. As will be discussed in more detail below, spreading the power level of the spurs over relatively wide bandwidth reduces the power levels of the spurs, for example, in 4 KHz frequency bandwidth windows without the need for relatively complex and expensive second and third order filters. Even though the power levels of some of the spurs are relatively high, due to the relatively high power level of the local oscillator signal in the mixer stages, these power levels are no longer concentrated at single frequencies but are spread over a relatively wider bandwidth reducing the power level in narrower bandwidth windows.

[0017] Referring to Fig. 3, a two-stage mixer in accordance with the present invention, generally identified with the reference numeral 42, is illustrated. In accordance with the present invention, the power level of the resulting spurs is spread over relatively wide bandwidth using phase modulation. More particularly, as shown, the two-stage mixer 42 includes a first mixer stage 44 and second mixer stage 46. An intermediate frequency (IF) filter 48 may be disposed between the first mixer stages 44 and the second mixer stage 46. In this example, a 750 MHz input RF signal is to be converted to an 18.25 GHz output signal for transmission. Although, not shown, the output of the second mixer stage 46 may be connected to another filter stage and amplifier stage, as well as a transmit antenna to transmit an output signal with a center frequency

at 18.25 GHz. As such, the frequency of the local oscillators for the first mixer stage 44 and the second mixer stage 46 are selected as 3 GHz and 16 GHz respectively, as in the previous example.

[0018] In accordance with an important aspect of the invention, the local oscillator signals are phase modulated by a phase modulator 50. The phase modulator 50 may be, for example, a direct sequency binary phase shift key (BPSK) modulator, modulated with a psuedorandom number (PN) code. The phase modulated output signals from the first mixer stage 44 are applied to the IF filter 48, which may be a simple low pass or bandpass filter which filters out various high order spurs. One of the aspects of the invention is that the phase modulation of the first mixer stage 44 for a given frequency bandwidth window spreads the power level of undesired spurs that cannot be easily filtered out. For example, the relatively high power level spur at 16 GHz resulting from leakage of the local oscillator in the second mixer stage 46 is no longer concentrated at a single frequency or tone as in the example illustrated in FIG. 2. Rather, the power level is spread out over a relatively wide bandwidth, shown as 2 MHz.

[0019] In general, the power reduction is provided by Equation (2) below:

$$10 \log (\text{phase modulation rate}/\text{bandwidth window})$$

Thus, for a 1 MHz phase modulation rate relative to a 4 KHz frequency bandwidth window, the power is reduced to $10 \log 1\text{MHz} / 4 \text{ KHz}$ or 24dB. Thus, as shown in Fig. 4, the spur 54 at the local oscillator frequency of 16 GHz for the second mixer stage is reduced to an acceptable level, for example, less than 65 dBc.

[0020] Although the spur 54 resulting from leakage of the local oscillator of the second mixer stage is the most problematic, the power levels of other spurs are also reduced. For example, with reference to FIG. 5, the spur 55 at 3.0 GHz resulting from leakage of the local oscillator in the first mixer stage 44, is spread over a relatively wide bandwidth, for example, 2 MHz, to an acceptable level, for example, less than 65 dBc.

[0021] With reference to FIG. 3, a 750 MHz input signal, generally identified with the reference numeral 57, is mixed with the output of the phase modulator 50 and applied to a filter

48. The output of the filter 48, thus includes the desired frequency of 2.25 MHz as well as reduced power spurs, such as the spur at the local oscillator frequency of 3.0 GHz from the first mixer stage 44. These signals, in turn, are mixed in the second mixer stage 46. In order to remove the phase modulation from the signal, the local oscillator signal for the second mixer stage 46 is inverse phase modulated by an inverse phase modulator, for example, a BPSK modulator 52. The inverse phase modulator 52 is phase modulated using the same PN code as the phase modulator 50 for the first mixer stage 44. The phase modulator 50 and inverse phase modulator 52 may be synchronized by using the same phase modulator source for both of the local oscillators for the first and second mixer stages 44 and 46, respectively.

[0022] The output of the second mixer stage 46 generates the desired output signal at 18.25 GHz, while minimizing the power levels of the spurs within 4 KHz frequency bandwidth windows. In particular, the output frequency F_{out} of the second mixer stage 46 is given by Equation (3) below:

$$(3) \quad F_{out} = IF_1 + LO_2, \text{ where } IF_1 \text{ is the output frequency of the IF filter 48 and } LO_2 \text{ is the frequency of the second stage local oscillator.}$$

The output frequency of the IF filter 48 is given by Equation (4).

$$(4) \quad IF_1 = LO_1 - F_{in}, \text{ where } LO_1 \text{ is the frequency of the first stage mixer 44 and } F_{in} \text{ is the frequency of the input signal 57.}$$

By substituting Equation (4) into Equation (3), the output frequency F_{out} is given by Equation (5) below.

$$(5) \quad F_{out} = LO_1 - F_{in} + LO_2$$

If the LO_1 signal, is phase modulated while the LO_2 signal is inverse phase modulated, the relative phase shifts are canceled and thus do not appear in the output signal F_{out} . However, the

leakage from the oscillator for the second stage 46 is inverse phase modulated and thus is spread out as shown in FIG. 4, thus reducing its energy in a 4 KHz bandwidth window. For example, with reference to FIG. 4, the spur at 16 GHz which represents leakage from the oscillator of the second mixer 46 is illustrated. This spur, identified with the reference numeral 54 is the result of the relatively high power level local oscillator signal used for the second mixer stage 46. As shown, due to the phase modulation, the power level of the spur 54 is spread over a relatively wide frequency bandwidth, thereby reducing the power level at individual frequencies or tones. Consequently, the power level of the spur 54 is within acceptable limits.

[0023] Other spurs, however, are not spread, and thus collapse to a single spectral line, for example, the spur signal resulting from the addition of the local oscillator frequency (LO_1) of the first mixer stage 44 with the local oscillator frequency (LO_2) of the second mixer stage 46. In particular, the LO_1 frequency is phase modulated by the phase modulator 50 while the LO_2 frequency is inverse phase modulated by the inverse phase modulator 52. Thus, the spur $LO_1 + LO_2$ is not spread but collapses to a single spectral line. However, this spur is less of a problem than the LO_2 leakage because it can be controlled by filtering the input to the second mixer stage 46 to remove the LO_1 leakage. Filtering out the LO_1 leakage at the input of the second mixer stage 46, designated as point A (FIG. 3), is easier than filtering the output of the second mixer stage 46 for several reasons. Firstly, the frequency at point A is lower than the frequency at the output of the second mixer stage. Secondly, the rejection shape factor at point A is greater at point A than at the output of the second mixer stage as shown below in Equation (6).

as opposed to

$$\frac{3GHz(spur)}{2.25GHz(desired)} = 1.33$$

[0024] Various phase modulators are suitable for a phase modulator 50 and the inverse

$$\frac{18.25GHz(spur)}{16.0GHz(desired)} = 1.14$$

phase modulator 52. The phase modulator 50 may be the same as the inverse phase modulator 52 but driven with an inverted bit sequence (0=1, 1=0). The PN code generator 60 generates the

PN codes. The phase modulator 50, inverse phase modulator 52 as well as a PN code generator are all well documented in the literature.

[0025] Although the invention has been described in terms of BPSK, the principles of the present invention are also applicable to other higher phase modulation techniques, such as quaternary phase shift keying (QPSK), phase shift (PSK). “M-ary” phase modulation techniques, such as minimum phase shift keying (MPSK), for example, as described in “Digital Communications”, second edition, Prentice Hall, Copyright 2001, hereby incorporated by reference. The principles of the present invention are also applicable to other modulator techniques, all well known in the art, such as Gaussian filtered minimum shift keying (GMSK), for example, as disclosed in U.S. Patent Nos. 5,022,054; 5,090,026; 5,117,441; 5,144,256; and 5,848,105, all hereby incorporated by reference. M-ary modulation systems are disclosed, for example, in U.S. Patent Nos. 5,712,871; 5,781,130; 6,002,725; 5,471,207; 5,390,198; 5,155,471; 4,989,220; 4,881,246, all hereby incorporated by reference. BPSK modulation systems are disclosed in U.S. Patent Nos. 5,502,745; 5,455,544; 5,455,543; 5,347,228; 4,816,769; 4,491,805, all hereby incorporated by reference. QPSK modulation systems are disclosed in U.S. Patent Nos. 4,55,667; 4,612,518; 4,769,816; 4,773,083; 5,084,903; 5,960,029; 6,091,781, all hereby incorporated by reference. It is only necessary that the first mixer stage be modulated while the second mixer stage is inverse modulated in order to take advantage of the principles of the present invention.

[0026] The principles of the present invention have also been described and illustrated in terms of a two-stage mixer. However, as illustrated in Fig. 5, the principles of the present invention can also be used to spread the power levels of unwanted spurs in a one stage mixer. For example, this could be accomplished by applying the inverse phase modulation directly to the modulation source. As such, when mixed with the local oscillator signal and its phase modulation, it is removed in the mixing process for the desired signal.

[0027] Obviously, many modification and variations of the present invention are possible in light of the above teachings. For example, thus, it is to be understood that, within the scope of

the appended claims, the invention may be practiced otherwise than as specifically described above.

[0028] What is claimed and desired to be secured by Letters Patent of the United States is: